EXECUTIVE SUMMARY: BACKGROUND AND FINDINGS

In the 21st century, management of municipal solid waste (MSW) continues to be an important environmental challenge facing the United States. In 2000, the United States generated 232 million tons of MSW, an increase of 13 percent over 1990 generation levels and 53 percent over 1980 levels.[1] Climate change is also a serious issue, and the United States is embarking on a number of voluntary actions to reduce the emissions of greenhouse gases (GHGs) that can intensify climate change. By presenting material-specific GHG emission factors for various waste management options, this report examines how the two issues—MSW management and climate change—are related.

Among the efforts to slow the potential for climate change are measures to reduce emissions of carbon dioxide (CO_2) from energy use, decrease emissions of methane (CH_4) and other non-carbon dioxide GHGs, and promote long-term storage of carbon in forests and soil. Management options for MSW provide many opportunities to affect these processes, directly or indirectly. This report integrates information on the GHG implications of various management options for some of the most common materials in MSW. To our knowledge, this work represents the most complete national study on climate change emissions and sinks from solid waste management practices. The report's findings may be used to support a variety of programs and activities, including voluntary reporting of emission reductions from waste management practices.

ES.1 GREENHOUSE GASES AND CLIMATE CHANGE

Climate change is a serious international environmental concern and the subject of much research and debate. Many, if not most, of the readers of this report will have a general understanding of the greenhouse effect and climate change. However, for those who are not familiar with the topic, a brief explanation follows.[2]

A naturally occurring shield of "greenhouse gases" (primarily water vapor, carbon dioxide, methane, and, nitrous oxide), comprising 1 to 2 percent of the Earth's atmosphere, absorbs some of the solar radiation that would otherwise be radiated to space and helps warm the planet to a comfortable, livable temperature range. Without this natural "greenhouse effect," the average temperature on Earth would be approximately -2 degrees Fahrenheit, rather than the current 57 degrees Fahrenheit.[3]

Many scientists are alarmed by a significant increase in the concentration of CO_2 and other GHGs in the atmosphere. Since the pre-industrial era, atmospheric concentrations of CO_2 have increased by nearly 30 percent and CH_4 concentrations have more than doubled. There is a growing international scientific consensus that this increase has been caused, at least in part, by

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[1] U.S. EPA Office of Solid Waste*, Municipal Solid Waste in the United States: 2000 Facts and Figures*, EPA (2002), p. 2.

[2] For more detailed information on climate change, please see *The 2001 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*, (http://www.epa.gov/globalwarming/publications/emissions/us2001/index.html) (April 2001); and *Climate Change 2001: The Scientific Basis* (J.T. Houghton, et al., eds. Intergovernmental Panel on Climate Change [IPCC]; published by Cambridge University Press, 2001). To obtain a list of additional documents addressing climate change, access EPA's global warming Web site at www.epa.gov/globalwarming.

[3] *Climate Change 2001: The Scientific Basis*, op. cit., pp. 89-90.

human activity, primarily the burning of fossil fuels (coal, oil, and natural gas) for such activities as generating electricity and driving cars.[4]

Moreover, in international scientific circles a consensus is growing that the buildup of CO_2 and other GHGs in the atmosphere will lead to major environmental changes such as (1) rising sea levels that may flood coastal and river delta communities; (2) shrinking mountain glaciers and reduced snow cover that may diminish fresh water resources; (3) the spread of infectious diseases and increased heat-related mortality; (4) possible loss in biological diversity and other impacts on ecosystems; and (5) agricultural shifts such as impacts on crop yields and productivity.[5] Although reliably detecting the trends in climate due to natural variability is difficult, the most accepted current projections suggest that the rate of climate change attributable to GHGs will far exceed any natural climate changes that have occurred during the last 1,000 years.[6]

Many of these changes appear to be occurring already. Global mean surface temperatures already have increased by about 1 degree Fahrenheit over the past century. A reduction in the northern hemisphere's snow cover, a decrease in Arctic sea ice, a rise in sea level, and an increase in the frequency of extreme rainfall events all have been documented.[7]

Such important environmental changes pose potentially significant risks to humans, social systems, and the natural world. Many uncertainties remain regarding the precise timing, magnitude, and regional patterns of climate change and the extent to which mankind and nature can adapt to any changes. It is clear, however, that changes will not be easily reversed for many decades or even centuries because of the long atmospheric lifetimes of GHGs and the inertia of the climate system.

ES.2 WHAT IS THE UNITED STATES DOING ABOUT CLIMATE CHANGE?

In 1992, world leaders and citizens from some 200 countries met in Rio de Janeiro, Brazil, to confront global ecological concerns. At this "Earth Summit," 154 nations, including the United States, signed the Framework Convention on Climate Change, an international agreement to address the danger of global climate change. The objective of the Convention was to stabilize GHG concentrations in the atmosphere over time at a level at which man-made climate disruptions would be minimized.

By signing the Convention, countries made a voluntary commitment to reduce GHGs or take other actions to stabilize emissions of GHGs. All Parties to the Convention were required to develop and periodically update national inventories of their GHG emissions. The United States ratified the Convention in October 1992. One year later, the United States issued its *Climate Change Action Plan* (CCAP), which calls for cost-effective domestic actions and voluntary cooperation with states, local governments, industry, and citizens to reduce GHG emissions.

In order to achieve the goals outlined in the Climate Change Action Plan, EPA initiated several new voluntary programs to realize the most cost-effective opportunities for reducing emissions. For example, in 1994 EPA created the Landfill Methane Outreach Program, which aims to reduce landfill CH_4 emissions by facilitating the development of projects that use landfill

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[4] *Ibid.,* p. 7.

[5] J.J. McCarthy, et al., eds. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. IPCC. Cambridge University Press. pp. 9-13.

[6] *Climate Change 2001: The Scientific Basis* , op. cit., p. 2.

[7] *Ibid.,* p. 4.

gas to produce energy.[8] In that same year, EPA introduced the Climate and Waste Program, with its focus on a broader set of waste management practices and climate protection.

To date, EPA's voluntary partnership programs for climate protection have achieved substantial environmental results. In 2000 alone, these programs reduced GHG emissions by 35 million metric tons of carbon equivalent (MMTCE)—the equivalent of eliminating the emissions from approximately 25 million cars. In addition, substantial CH_4 emission reductions—estimated at more than 1 MMTCE for the period from 1999-2000—are being obtained as an ancillary benefit of Clean Air Act (CAA) regulatory requirements that were promulgated in 1996. These reductions are expected to rise to nearly 47 MMTCE by 2004.

Meanwhile, an increasing number of states have been instituting their own voluntary actions to reduce emissions. Thirty-nine states and Puerto Rico have created GHG Inventories for their own emissions. Twenty-five states and Puerto Rico have completed or initiated state action plans, which list steps to reduce emissions. At least six of these states—Delaware, Iowa, Minnesota, Montana, New Jersey, and Oregon—have incorporated the reduction of waste into their GHG mitigation strategies. Finally, a few states—including California, Maine, New Hampshire, and Wisconsin—are in the process of establishing GHG registries, which enable companies and other entities to report voluntary emission reductions.

ES.3 WHAT IS THE RELATIONSHIP OF MUNICIPAL SOLID WASTE TO GREENHOUSE GAS EMISSIONS?

What does MSW have to do with rising sea levels, higher temperatures, and GHG emissions? For many wastes, the materials in MSW represent what is left over after a long series of steps: (1) extraction and processing of raw materials; (2) manufacture of products; (3) transportation of materials and products to markets; (4) use by consumers; and (5) waste management.

Virtually every step along this "life cycle" impacts GHG emissions. Waste management decisions can reduce GHGs by affecting one or more of the following:

(1) <u>Energy consumption</u> (specifically, combustion of fossil fuels) associated with making, transporting, using, and disposing the product or material that becomes a waste.

(2) <u>Non-energy-related manufacturing emissions</u>, such as the CO_2 released when limestone is converted to lime (which is needed for use in aluminum and steel manufacturing).

(3) <u>CH_4 emissions</u> from landfills where the waste is disposed.

(4) <u>Carbon sequestration</u>, which refers to natural or man-made processes that remove carbon from the atmosphere and store it for long periods or permanently.

The first three mechanisms *add* GHGs to the atmosphere and contribute to global warming. The fourth—carbon sequestration—*reduces* GHG concentrations by removing CO_2 from the atmosphere. Forest growth is one mechanism for sequestering carbon; if more biomass is grown than is removed (through harvest or decay), the amount of carbon stored in trees increases, and thus carbon is sequestered.

[8] The Landfill Methane Outreach Program (LMOP) is a voluntary assistance and partnership program that helps facilitate and promote the use of landfill gas as a renewable energy source. By controlling landfill gas instead of allowing it to migrate into the air, the LMOP helps businesses, states, and communities protect the environment and build a sustainable future. The program has an Internet home page (http://www.epa.gov/landfill.html) and can be reached via a toll-free hotline number (800-782-7937).

Different wastes and waste management options have different implications for energy consumption, CH_4 emissions, and carbon sequestration. Source reduction and recycling of paper products, for example, reduce energy consumption, decrease combustion and landfill emissions, and increase forest carbon sequestration.

ES.4 WHY EPA PREPARED THIS REPORT AND HOW IT HAS BEEN USED

Recognizing the potential for source reduction and recycling of municipal solid waste to reduce GHG emissions, EPA included a source reduction and recycling initiative in the original 1994 Climate Change Action Plan and set an emission reduction goal based on a preliminary analysis of the potential benefits of these activities. It was clear that a rigorous analysis would be needed to gauge more accurately the total GHG emission reductions achievable through source reduction and recycling. That *all* of the options for managing MSW should be considered also became clear. By addressing a broader set of MSW management options, a more comprehensive picture of the GHG benefits of voluntary actions in the waste sector could be determined and the relative GHG impacts of various waste management approaches could be assessed. To this end, EPA launched a major research effort, the results of which were published in the first edition of this report in September 1998. This edition of the report includes additional materials and incorporates updated data affecting many of the material-specific results. The emission factors presented will continue to be updated and improved as more data become available. The latest emission factors, reflecting these ongoing revisions, can be found on the EPA Global Warming Web site <http://www.epa.gov/globalwarming/actions/waste/w-online.htm>.

The primary application of the GHG emission factors in this report is to support mitigation accounting for waste management practices that mitigate climate change. In recent years, the emission factors have been applied for this purpose in a number of ways. In conjunction with the U.S. Department of Energy, EPA has used these estimates to develop guidance for voluntary reporting of GHG reductions, as authorized by Congress in Section 1605(b) of the Energy Policy Act of 1992.

Other applications have included quantifying the GHG reductions from voluntary programs aimed at source reduction and recycling, such as EPA's WasteWise and Pay-As-You-Throw programs. EPA also has worked with the Climate Neutral Network to develop company-specific GHG "footprints" for the network's member companies, who have pledged to become GHG "neutral" through emission reductions or offset activities.

The international community has shown considerable interest in using the emission factors—or adapted versions—to develop GHG emissions estimates for non-U.S. solid waste streams.[9] For example, Environment Canada recently employed our life-cycle methodology and components of our analysis to develop a set of Canada-specific GHG emission factors to support analysis of waste-related mitigation opportunities.[10]

Additionally, EPA worked with the International Council for Local Environmental Initiatives (ICLEI) to incorporate GHG emission factors into its municipal GHG accounting software. Currently, 350 communities participate in ICLEI's Cities for Climate Protection Campaign, which helps them establish a GHG emission reduction target and implement a

[9] Note that waste composition and product life cycles vary significantly among countries. This report may assist other countries by providing a methodologic framework and benchmark data for developing GHG emission estimates for their solid waste streams.

[10] Environment Canada. 2001. *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions*. Prepared by ICF Consulting, Torrie-Smith Associates, and Enviros-RIS.

comprehensive local action plan designed to achieve that target. Currently, we are exploring other options for broadening the use of our research internationally.

To make it easier for organizations to use these emission factors, EPA created the Waste Reduction Model (WARM) spreadsheet tool.[11] WARM enables waste managers and other users to calculate changes in total GHG emissions quickly by entering in information on baseline and alternative waste management practices. By applying the appropriate material-specific emission factors for each practice, the tool generates an estimate of the net GHG impact from implementing the alternative waste management practice as compared to the baseline practice.

ES.5 HOW WE ANALYZED THE IMPACT OF MUNICIPAL SOLID WASTE ON GREENHOUSE GAS EMISSIONS

To measure the GHG impacts of MSW, one must first decide which wastes to analyze. We surveyed the universe of materials and products found in MSW and determined those that are most likely to have the greatest impact on GHGs. These determinations were based on (1) the quantity generated; (2) the differences in energy use for manufacturing a product from virgin versus recycled inputs; and (3) the potential contribution of materials to CH_4 generation in landfills. By this process, we limited the analysis to the following 16 items:

- Aluminum Cans;
- Steel Cans;
- Glass;
- HDPE (high-density polyethylene) Plastic;
- LDPE (low-density polyethylene) Plastic;
- PET (polyethylene terephthalate) Plastic;
- Corrugated Cardboard;
- Magazines/Third-class Mail;
- Newspaper;
- Office Paper;
- Phonebooks;
- Textbooks;
- Dimensional Lumber;
- Medium-density Fiberboard;
- Food Discards; and
- Yard Trimmings.

The foregoing materials constitute 64.4 percent, by weight, of MSW, as shown in Exhibit ES-1.[12]

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[11] WARM is available on the EPA Web site: http://www.epa.gov/globalwarming/actions/waste/warm.htm.

[12] Note that these data are based on national averages. The composition of solid waste varies locally and regionally; local or state-level data should be used when available.

We also examined the GHG implications of managing mixed paper, mixed plastics, mixed organics, mixed recyclables, and mixed MSW.

- *Mixed paper* is recycled in large quantities and is an important class of scrap material in many recycling programs. Presenting a single definition of mixed paper is difficult, however, because recovered paper varies considerably, depending on the source. For purposes of this report, we identified three categories of mixed paper according to the dominant source—broad (general sources), office, and residential.
- *Mixed plastics* is comprised of HDPE, LDPE, and PET, and is estimated by taking a weighted average of the 2000 recovery rates for these three plastic types.
- *Mixed organics* is a weighted average of food discards and yard trimmings, using generation rates for 2000.
- *Mixed recyclables* are materials that are typically recycled. As used in this report, the term includes the items listed in Exhibit ES-1, except food discards and yard trimmings. The emission factors reported for mixed recyclables represent the average GHG emissions for these materials, weighted by the tonnages at which they were recycled in 2000.
- *Mixed MSW* is comprised of the waste material typically discarded by households and collected by curbside collection vehicles; it does not include white goods (e.g., refrigerators, toasters) or industrial waste. This report analyzes mixed MSW on an "as-disposed" (rather than "as-generated") basis.

Exhibit ES-1
Percentage of 2000 U.S. Generation of MSW for Materials in This Report

Material	Percentage of MSW Generation (by Weight)
Aluminum Cans	0.7%
Steel Cans	1.1%
Glass	5.5%
HDPE	1.6%
LDPE	1.3%
PET	0.8%
Corrugated Cardboard	13.0%
Magazines/Third-class Mail	3.3%
Newspaper	6.5%
Office Paper	3.2%
Phonebooks	0.3%
Textbooks	0.5%
Dimensional Lumber (listed as "Wood – Containers and Packaging)	3.4%
Medium-density Fiberboard	NA
Food Discards	11.2%
Yard Trimmings	12.0%
TOTAL	64.4%

Source: U.S. EPA. 2002. *Municipal Solid Waste in the United States: 2000 Facts and Figures,* EPA 530-R-02-001.

We developed a streamlined life-cycle inventory for each of the selected materials. Our analysis is streamlined in the sense that it examines GHG emissions only and is not a more comprehensive environmental analysis of all emissions from municipal solid waste management options.[13]

[13] EPA's Office of Research and Development (ORD) performed a more extensive application of life-cycle assessment for various waste management options for MSW. A decision support tool (DST) and life-cycle inventory (LCI) database for North America have been developed with funding by ORD through a cooperative agreement with the Research Triangle Institute (RTI) (CR823052). This methodology is based on a multi-media, multi-pollutant approach and includes analysis of GHG emissions as well as a broader set of emissions (air, water, and waste) associated with MSW operations. At the time of publication of this report, the MSW-DST is available for site-specific applications. For further information, contact Keith Weitz at rti.org or (919) 541-6973. The LCI database is expected to be released in 2002. The Web site address for further information is: <http://www.rti.org/units/ese/p2/lca.cfm#life>.

We focused on those aspects of the life cycle that have the potential to emit GHGs as materials change from their raw states to products and then to waste. Exhibit ES-2 shows the steps in the life cycle at which GHGs are emitted, carbon sequestration is affected, and utility energy is displaced. As shown, we examined the potential for these effects at the following points in a product's life cycle:

- Raw material acquisition (fossil fuel energy and other emissions, and changes in forest carbon sequestration);
- Manufacturing (fossil fuel energy emissions); and
- Waste management (CO_2 emissions associated with composting, non-biogenic CO_2 and nitrous oxide (N_2O) emissions from combustion, and CH_4 emissions from landfills); these emissions are offset to some degree by carbon storage in soil and landfills, as well as avoided utility emissions from energy recovery at combustors and landfills.

At each of these points, we also considered transportation-related energy emissions. Estimates of GHG emissions associated with electricity used in the raw materials acquisition and manufacturing steps are based on the nation's current mix of energy sources,[14] including fossil fuels, hydropower, and nuclear power. Estimates of GHG emission reductions attributable to utility emissions avoided from waste management practices, however, are based solely on the reduction of fossil fuel use.[15]

We did not analyze the GHG emissions associated with consumer use of products because energy use for the selected materials is small (or zero) at this point in the life cycle. In addition, the energy consumed during use would be approximately the same whether the product was made from virgin or recycled inputs.

To apply the GHG estimates developed in this report, one must compare a baseline scenario with an alternative scenario, on a life-cycle basis. For example, we could compare a baseline scenario, where 10 tons of office paper are manufactured, used, and landfilled, to an alternative scenario, where 10 tons are manufactured, used, and recycled.

Improvements to the First Edition

This report is the second edition of *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste*. This edition includes the following improvements:

- Incorporates new data on energy and recycling loss rates from EPA's Office of Research and Development;
- Expands the analysis of the GHG benefits of composting, including results of CENTURY model runs;
- Develops emission factors for five new material types: magazines/third-class mail, phonebooks, textbooks, dimensional lumber, and medium-density fiberboard;
- Develops emission factors for two new categories of mixed materials: mixed plastics and mixed organics;
- Incorporates new energy data into calculations of utility offsets;
- Revises carbon coefficients and fuel use for national average electricity generation;
- Updates information on landfill gas recovery rates;
- Adds a discussion of emerging issues in the area of climate change and waste management; and
- Provides a list of suggested proxy values for voluntary reporting of GHG emission reductions.

These changes and/or revisions are described in more detail throughout the report.

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[14] The emissions are based on the current national grid mix, as opposed to regional grids.

[15] We adopted this approach based on suggestions from several reviewers who argued that fossil fuels should be regarded as the marginal fuel displaced by waste-to-energy and landfill gas recovery systems.

Exhibit ES-2 Greenhouse Gas Sources and Sinks Associated with the Material Life Cycle

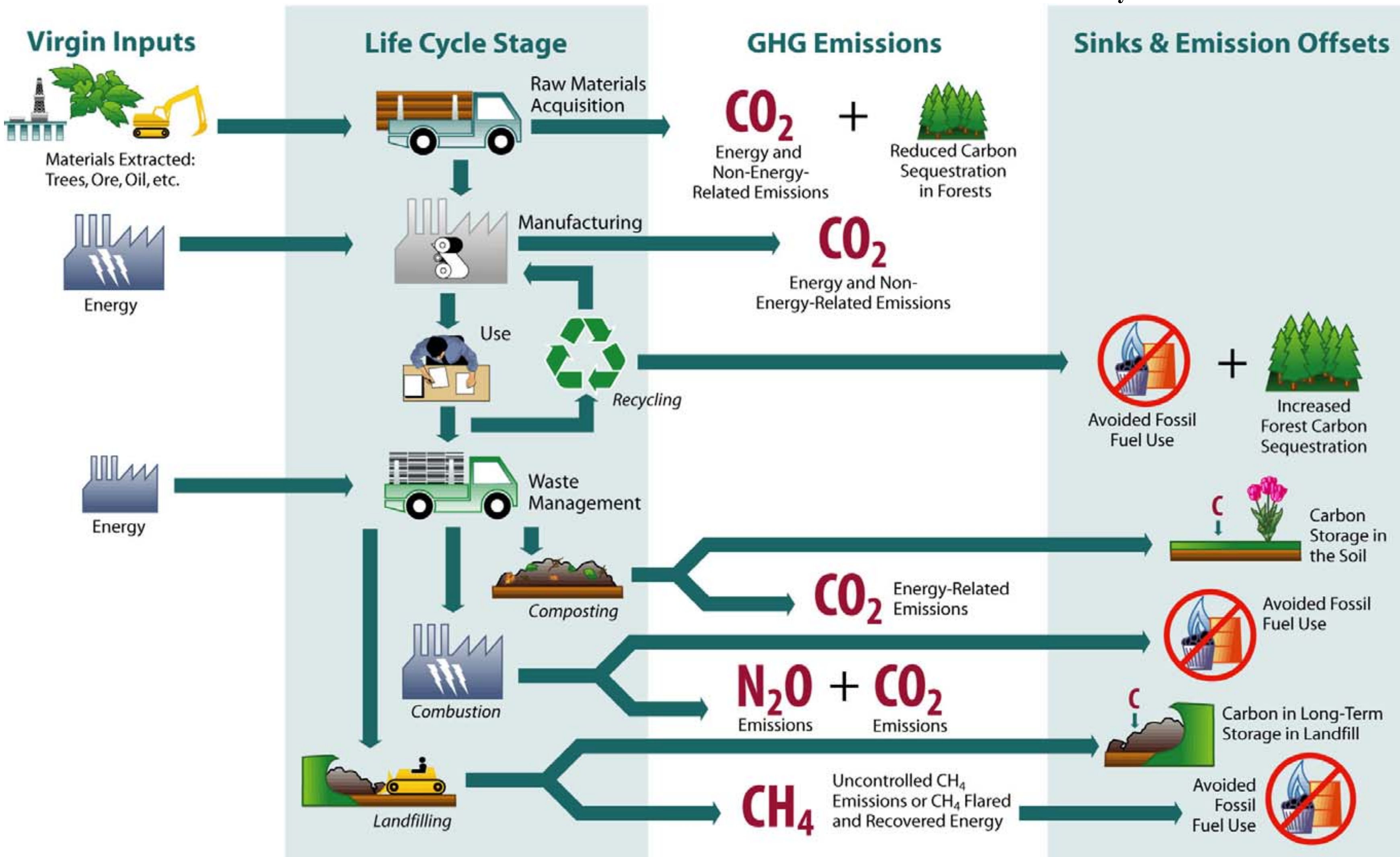

Exhibit ES-3 shows how GHG sources and sinks are affected by each waste management strategy. For example, the top row of the exhibit shows that source reduction[16] (1) reduces GHG emissions from raw materials acquisition and manufacturing; (2) results in an increase in forest carbon sequestration; and (3) does not result in GHG emissions from waste management. The sum of emissions (and sinks) across all steps in the life cycle represents net emissions.

Exhibit ES-3 Components of Net Emissions for Various MSW Management Strategies

MSW Management Strategy	GHG Sources and Sinks		
	Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**Waste Management**
Source Reduction	Decrease in GHG emissions, relative to the baseline of manufacturing	Increase in forest carbon sequestration (for organic materials)	No emissions/sinks
Recycling	Decrease in GHG emissions due to lower energy requirements (compared to manufacture from virgin inputs) and avoided process non-energy GHGs	Increase in forest carbon sequestration (for organic materials)	Process and transportation emissions associated with recycling are counted in the manufacturing stage
Composting (food discards, yard trimmings)	No emissions/sinks	Increase in soil carbon storage	Compost machinery emissions and transportation emissions
Combustion	No change	No change	Non-biogenic CO_2, N_2O emissions, avoided utility emissions, and transportation emissions
Landfilling	No change	No change	CH_4 emissions, long-term carbon storage, avoided utility emissions, and transportation emissions

ES.6 RESULTS OF THE ANALYSIS

Management of municipal solid waste presents many opportunities for GHG emission reductions. Source reduction and recycling can reduce GHG emissions at the manufacturing stage, increase forest carbon sequestration, and avoid landfill CH_4 emissions. When waste is combusted, energy recovery displaces electricity generated by utilities by burning fossil fuels (thus reducing GHG emissions from the utility sector), and landfill CH_4 emissions are avoided. Landfill CH_4 emissions can be reduced by using gas recovery systems and by diverting organic materials from landfills. Landfill CH_4 can be flared or utilized for its energy potential. When used for its energy potential, landfill CH_4 displaces fossil fuels, as with MSW combustion.

[16] In this analysis, the source reduction techniques we analyze involve using less of a given product without using more of some other product—e.g., making aluminum cans with less aluminum (“lightweighting”); double-sided rather than single-sided photocopying; or reuse of a product. We did not consider source reduction of one product that would be associated with substitution by another product—e.g., substituting plastic boxes for corrugated paper boxes. Nor did we estimate the potential for source reduction of chemical fertilizers and pesticides with increased production and use of compost. For a discussion of source reduction with material substitution, see Section 4.3.

In order to support a broad portfolio of climate change mitigation activities covering a range of GHGs, many different methodologies for estimating emissions will be needed. The primary result of this research is the development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices.

Exhibits ES-4 and ES-5 present the GHG impacts of source reduction, recycling, composting, combustion, and landfilling. The impacts are presented on a per-ton managed basis for the individual and mixed materials, using the waste generation reference point. Exhibit ES-4 presents these values in MTCE/ton, and Exhibit ES-5 presents the values in metric tons of carbon dioxide equivalent/ton ($MTCO_2E$/ton). For comparison, Exhibits ES-6 and ES-7 show the same results (in MTCE/ton and $MTCO_2E$/ton, respectively) using the raw material extraction reference point. In these tables, emissions for 1 ton of a given material are presented across different management options.[17] The life-cycle GHG emissions for each of the first four waste management strategies—source reduction, recycling, composting, and combustion—are compared to the GHG emissions from landfilling in Exhibits ES-8 and ES-9. These exhibits show the GHG values for each of the first four management strategies, minus the GHG values for landfilling. With these exhibits, one may compare the GHG emissions of changing management of 1 ton of each material from landfilling (often viewed as the baseline waste management strategy) to one of the other waste management options.

All values shown in Exhibits ES-4 through ES-9 are for national average conditions (e.g., average fuel mix for raw material acquisition and manufacturing using recycled inputs; typical efficiency of a mass burn combustion unit; national average landfill gas collection rates). GHG emissions are sensitive to some factors that vary on a local basis, and thus site-specific emissions will differ from those summarized here.

Following is a discussion of the principal GHG emissions and sinks for each waste management practice and the effect that they have on the emission factors:

- Source reduction, in general, represents an opportunity to reduce GHG emissions in a significant way.[18] For many materials, the reduction in energy-related CO_2 emissions from the raw material acquisition and manufacturing process, and the absence of emissions from waste management, combine to reduce GHG emissions more than other options.
- For most materials, recycling has the second lowest GHG emissions. For these materials, recycling reduces energy-related CO_2 emissions in the manufacturing process (although not as dramatically as source reduction) and avoids emissions from waste management. Paper recycling increases the sequestration of forest carbon.
- Composting is a management option for food discards and yard trimmings. The net GHG emissions from composting are lower than landfilling for food discards (composting avoids CH_4 emissions), and higher than landfilling for yard trimmings (landfilling is credited with the carbon storage that results from incomplete decomposition of yard trimmings). Overall, given the uncertainty in the analysis, the emission factors for composting or combusting these materials are similar.

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[17] Note that the difference between any two values for a given material in Exhibit ES-4 (i.e., emissions for the same material in two waste management options) is the same as the difference between the two corresponding values in Exhibit ES-5.

[18] As noted above, the only source reduction strategy analyzed in this study is lightweighting. Consequently, the results shown here do not directly apply to material substitution.

Exhibit ES-4

Net GHG Emissions from Source Reduction and MSW Management Options - Emissions Counted from a Waste Generation Reference Point (MTCE/Ton)[1]

Material	Source Reduction[2]	Recycling	Composting[3]	Combustion[4]	Landfilling[5]
Aluminum Cans	-2.49	-4.11	NA	0.02	0.01
Steel Cans	-0.79	-0.49	NA	-0.42	0.01
Glass	-0.14	-0.08	NA	0.01	0.01
HDPE	-0.49	-0.38	NA	0.23	0.01
LDPE	-0.61	-0.47	NA	0.23	0.01
PET	-0.49	-0.42	NA	0.28	0.01
Corrugated Cardboard	-0.51	-0.71	NA	-0.19	0.08
Magazines/Third-class Mail	-1.04	-0.74	NA	-0.13	-0.12
Newspaper	-0.81	-0.95	NA	-0.21	-0.21
Office Paper	-0.80	-0.68	NA	-0.18	0.62
Phonebooks	-1.28	-0.91	NA	-0.21	-0.21
Textbooks	-1.23	-0.75	NA	-0.18	0.62
Dimensional Lumber	-0.55	-0.67	NA	-0.22	-0.10
Medium-density Fiberboard	-0.60	-0.67	NA	-0.22	-0.10
Food Discards	NA	NA	-0.05	-0.05	0.17
Yard Trimmings	NA	NA	-0.05	-0.06	-0.09
Mixed Paper					
Broad Definition	NA	-0.67	NA	-0.19	0.10
Residential Definition	NA	-0.67	NA	-0.18	0.07
Office Paper Definition	NA	-0.83	NA	-0.17	0.15
Mixed Plastics	NA	-0.41	NA	0.25	0.01
Mixed Recyclables	NA	-0.76	NA	-0.17	0.05
Mixed Organics	NA	NA	-0.05	-0.06	0.03
Mixed MSW as Disposed	NA	NA	NA	-0.04	0.07

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]MTCE/ton: Metric tons of carbon equivalent per short ton of material. Material tonnages are on an as-managed (wet weight) basis.

[2]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3]There is considerable uncertainty in our estimate of net GHG emissions from composting; the values of zero are plausible values based on assumptions and a bounding analysis.

[4]Values are for mass burn facilities with national average rate of ferrous recovery.

[5]Values reflect estimated national average methane recovery in year 2000.

Exhibit ES-5

Net GHG Emissions from Source Reduction and MSW Management Options - Emissions Counted from a Waste Generation Reference Point ($MTCO_2E$/Ton)[1]

Material	Source Reduction[2]	Recycling	Composting[3]	Combustion[4]	Landfilling[5]
Aluminum Cans	-9.15	-15.07	NA	0.06	0.04
Steel Cans	-2.89	-1.79	NA	-1.53	0.04
Glass	-0.50	-0.28	NA	0.05	0.04
HDPE	-1.79	-1.40	NA	0.85	0.04
LDPE	-2.25	-1.71	NA	0.85	0.04
PET	-1.78	-1.55	NA	1.04	0.04
Corrugated Cardboard	-1.89	-2.60	NA	-0.68	0.28
Magazines/Third-class Mail	-3.80	-2.70	NA	-0.49	-0.44
Newspaper	-2.97	-3.48	NA	-0.77	-0.76
Office Paper	-2.95	-2.48	NA	-0.65	2.28
Phonebooks	-4.70	-3.34	NA	-0.77	-0.76
Textbooks	-4.49	-2.74	NA	-0.65	2.28
Dimensional Lumber	-2.01	-2.45	NA	-0.81	-0.38
Medium-density Fiberboard	-2.20	-2.47	NA	-0.81	-0.38
Food Discards	NA	NA	-0.20	-0.19	0.62
Yard Trimmings	NA	NA	-0.20	-0.23	-0.34
Mixed Paper					
Broad Definition	NA	-2.47	NA	-0.68	0.37
Residential Definition	NA	-2.47	NA	-0.68	0.25
Office Paper Definition	NA	-3.05	NA	-0.62	0.56
Mixed Plastics	NA	-1.51	NA	0.93	0.04
Mixed Recyclables	NA	-2.80	NA	-0.61	0.19
Mixed Organics	NA	NA	-0.20	-0.21	0.12
Mixed MSW as Disposed	NA	NA	NA	-0.13	0.24

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]$MTCO_2E$/ton: Metric tons of carbon dioxide equivalent per short ton of material. Material tonnages are on an as-managed (wet weight) basis.

[2]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3]There is considerable uncertainty in our estimate of net GHG emissions from composting; the values of zero are plausible values based on assumptions and a bounding analysis.

[4]Values are for mass burn facilities with national average rate of ferrous recovery.

[5]Values reflect estimated national average methane recovery in year 2000.

Exhibit ES-6

Net GHG Emissions from Source Reduction and MSW Management Options - Emissions Counted from a Raw Materials Extraction Reference Point (MTCE/Ton)

Material	Source Reduction[1]	Recycling[2]	Composting[2]	Combustion[2]	Landfilling[2]
Aluminum Cans	0.00	-1.61	NA	2.51	2.50
Steel Cans	0.00	0.30	NA	0.37	0.80
Glass	0.00	0.06	NA	0.15	0.15
HDPE	0.00	0.10	NA	0.72	0.50
LDPE	0.00	0.15	NA	0.85	0.63
PET	0.00	0.06	NA	0.77	0.50
Corrugated Cardboard	-0.28	-0.47	NA	0.05	0.32
Magazines/Third-class Mail	-0.58	-0.28	NA	0.33	0.34
Newspaper	-0.35	-0.49	NA	0.25	0.25
Office Paper	-0.50	-0.37	NA	0.13	0.93
Phonebooks	-0.65	-0.27	NA	0.42	0.43
Textbooks	-0.64	-0.16	NA	0.41	1.21
Dimensional Lumber	-0.50	-0.62	NA	-0.17	-0.06
Medium-density Fiberboard	-0.50	-0.58	NA	-0.12	-0.01
Food Discards	NA	NA	-0.05	-0.05	0.17
Yard Trimmings	NA	NA	-0.05	-0.06	-0.09
Mixed Paper					
Broad Definition	NA	-0.30	NA	0.19	0.48
Residential Definition	NA	-0.30	NA	0.19	0.45
Office Paper Definition	NA	0.02	NA	0.68	1.01
Mixed Plastics	NA	0.09	NA	0.76	0.52
Mixed Recyclables	NA	-0.40	NA	0.19	0.41
Mixed Organics	NA	NA	-0.05	-0.06	0.03
Mixed MSW as Disposed	NA	NA	NA	-0.04	0.07

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[2]Includes emissions from the initial production of the material being managed, except for foodwaste, yard waste, and mixed MSW.

Exhibit ES-7

Net GHG Emissions from Source Reduction and MSW Management Options - Emissions Counted from a Raw Materials Extraction Reference Point ($MTCO_2E$/Ton)

Material	Source Reduction[1]	Recycling[2]	Composting[2]	Combustion[2]	Landfilling[2]
Aluminum Cans	0.00	-5.92	NA	9.21	9.18
Steel Cans	0.00	1.09	NA	1.35	2.92
Glass	0.00	0.22	NA	0.55	0.54
HDPE	0.00	0.38	NA	2.64	1.82
LDPE	0.00	0.54	NA	3.11	2.29
PET	0.00	0.23	NA	2.82	1.82
Corrugated Cardboard	-1.01	-1.72	NA	0.20	1.16
Magazines/Third-class Mail	-2.11	-1.02	NA	1.20	1.25
Newspaper	-1.29	-1.79	NA	0.91	0.92
Office Paper	-1.82	-1.36	NA	0.47	3.41
Phonebooks	-2.37	-1.01	NA	1.56	1.57
Textbooks	-2.35	-0.60	NA	1.49	4.43
Dimensional Lumber	-1.84	-2.28	NA	-0.64	-0.21
Medium-density Fiberboard	-1.84	-2.11	NA	-0.45	-0.03
Food Discards	NA	NA	-0.20	-0.19	0.62
Yard Trimmings	NA	NA	-0.20	-0.23	-0.34
Mixed Paper					
Broad Definition	NA	-1.09	NA	0.70	1.76
Residential Definition	NA	-1.08	NA	0.71	1.64
Office Paper Definition	NA	0.07	NA	2.50	3.69
Mixed Plastics	NA	0.34	NA	2.79	1.89
Mixed Recyclables	NA	-1.48	NA	0.71	1.51
Mixed Organics	NA	NA	-0.20	-0.21	0.12
Mixed MSW as Disposed	NA	NA	NA	-0.13	0.24

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[2]Includes emissions from the initial production of the material being managed, except for foodwaste, yard waste, and mixed MSW.

Exhibit ES-8

GHG Emissions of MSW Management Options Compared to Landfilling[1] (MTCE/Ton)

Material	Source Reduction[2] Net Emissions Minus Landfilling Net Emissions (Current Mix)	Source Reduction Net Emissions Minus Landfilling Net Emissions (100% Virgin Inputs)	Recycling Net Emissions Minus Landfilling Net Emissions	Composting[3] Net Emissions Minus Landfilling Net Emissions	Combustion[4] Net Emissions Minus Landfilling Net Emissions
Aluminum Cans	-2.50	-4.68	-4.12	NA	0.01
Steel Cans	-0.80	-1.02	-0.50	NA	-0.43
Glass	-0.15	-0.17	-0.09	NA	0.00
HDPE	-0.50	-0.54	-0.39	NA	0.22
LDPE	-0.63	-0.65	-0.48	NA	0.22
PET	-0.50	-0.59	-0.43	NA	0.27
Corrugated Cardboard	-0.59	-1.03	-0.79	NA	-0.26
Magazines/Third-class Mail	-0.92	-1.07	-0.62	NA	-0.01
Newspaper	-0.60	-1.11	-0.74	NA	0.00
Office Paper	-1.43	-1.63	-1.30	NA	-0.80
Phonebooks	-1.07	-1.19	-0.70	NA	0.00
Textbooks	-1.85	-1.94	-1.37	NA	-0.80
Dimensional Lumber	-0.44	NA	-0.56	NA	-0.12
Medium-density Fiberboard	-0.50	NA	-0.57	NA	-0.12
Food Discards	NA	NA	NA	-0.22	-0.22
Yard Trimmings	NA	NA	NA	0.04	0.03
Mixed Paper					
Broad Definition	NA	NA	-0.78	NA	-0.29
Residential Definition	NA	NA	-0.74	NA	-0.25
Office Paper Definition	NA	NA	-0.99	NA	-0.32
Mixed Plastics	NA	NA	-0.42	NA	0.24
Mixed Recyclables	NA	NA	-0.82	NA	-0.22
Mixed Organics	NA	NA	NA	-0.09	-0.09
Mixed MSW as Disposed	NA	NA	NA	NA	-0.10

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1] Values for landfilling reflect projected national average methane recovery in year 2000.

[2] Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3] Calculation is based on assuming zero net emissions for composting.

[4] Values are for mass burn facilities with national average rate of ferrous recovery.

Exhibit ES-9

GHG Emissions of MSW Management Options Compared to Landfilling[1] ($MTCO_2E$/Ton)

Material	Source Reduction[2] Net Emissions Minus Landfilling Net Emissions (Current Mix)	Source Reduction Net Emissions Minus Landfilling Net Emissions (100% Virgin Inputs)	Recycling Net Emissions Minus Landfilling Net Emissions	Composting[3] Net Emissions Minus Landfilling Net Emissions	Combustion[4] Net Emissions Minus Landfilling Net Emissions
Aluminum Cans	-9.18	-17.15	-15.11	NA	0.02
Steel Cans	-2.92	-3.72	-1.83	NA	-1.57
Glass	-0.54	-0.61	-0.32	NA	0.01
HDPE	-1.82	-1.99	-1.44	NA	0.81
LDPE	-2.29	-2.38	-1.75	NA	0.81
PET	-1.82	-2.18	-1.59	NA	1.00
Corrugated Cardboard	-2.17	-3.79	-2.88	NA	-0.96
Magazines/Third-class Mail	-3.36	-3.94	-2.26	NA	-0.05
Newspaper	-2.21	-4.07	-2.72	NA	-0.01
Office Paper	-5.23	-5.99	-4.77	NA	-2.94
Phonebooks	-3.94	-4.37	-2.57	NA	-0.01
Textbooks	-6.78	-7.13	-5.03	NA	-2.94
Dimensional Lumber	-1.63	NA	-2.07	NA	-0.43
Medium-density Fiberboard	-1.82	NA	-2.09	NA	-0.43
Food Discards	NA	NA	NA	-0.82	-0.81
Yard Trimmings	NA	NA	NA	0.15	0.11
Mixed Paper					
Broad Definition	NA	NA	-2.84	NA	-1.06
Residential Definition	NA	NA	-2.72	NA	-0.93
Office Paper Definition	NA	NA	-3.62	NA	-1.18
Mixed Plastics	NA	NA	-1.55	NA	0.90
Mixed Recyclables	NA	NA	-2.99	NA	-0.80
Mixed Organics	NA	NA	NA	-0.32	-0.33
Mixed MSW as Disposed	NA	NA	NA	NA	-0.38

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]Values for landfilling reflect projected national average methane recovery in year 2000.

[2]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3]Calculation is based on assuming zero net emissions for composting.

[4]Values are for mass burn facilities with national average rate of ferrous recovery.

- The net GHG emissions from combustion of mixed MSW are lower than landfilling mixed MSW (under national average conditions for landfill gas recovery). Because, in practice, combustors and landfills manage a mixed waste stream, net emissions are determined more by technology factors (e.g., the efficiency of landfill gas collection systems and combustion energy conversion) than by material specificity. Material-specific emissions for landfills and combustors provide a basis for comparing these options with source reduction, recycling, and composting.

The ordering of combustion, landfilling, and composting is affected by (1) the GHG inventory accounting methods, which do not count CO_2 emissions from sustainable biogenic sources,[19] but do count emissions from sources such as plastics; and (2) a series of assumptions on sequestration, future use of CH_4 recovery systems, system efficiency for landfill gas recovery, ferrous metals recovery, and avoided utility fossil fuels. On a site-specific basis, the ordering of results between a combustor and a landfill could be different from the ordering provided here, which is based on national average conditions.

We conducted sensitivity analyses to examine the GHG emissions from landfilling under varying assumptions about (1) the percentage of landfilled waste sent to landfills with gas recovery, and (2) CH_4 oxidation rate and gas collection system efficiency. The sensitivity analyses demonstrate that the results for landfills are very sensitive to these factors, which are site-specific.[20] Thus, using a national average value when making generalizations about emissions from landfills masks some of the variability that exists from site to site.

The scope of this report is limited to developing emission factors that can be used to evaluate GHG implications of solid waste decisions. We do not analyze policy options in this report. Nevertheless, the differences in emission factors across various waste management options are sufficiently large as to imply that GHG mitigation policies in the waste sector can make a significant contribution to U.S. emission reductions. A number of examples, using the emission factors in this report, bear this out.

- At the firm level, targeted recycling programs can reduce GHGs. For example, a commercial facility that shifts from (a) a baseline practice of landfilling (in a landfill with no gas collection system) 50 tons office paper and 4 tons of aluminum cans to (b) recycling the same materials can reduce GHG emissions by more than 100 MTCE.
- At the community level, a city of 100,000 with average waste generation (4.5 lbs/day per capita), recycling (30 percent), and baseline disposal in a landfill with no gas collection system could increase its recycling rate to 40 percent—for example, by implementing a pay-as-you-throw program—and reduce emissions by about 10,000 MTCE per year. (Note that further growth in recycling would be possible; some communities already are exceeding recycling rates of 50 percent).
- A city of 1 million, disposing of 650,000 tons per year in a landfill without gas collection, could reduce its GHG emissions by nearly 138,000 MTCE per year by managing waste in a mass burn combustor unit.

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[19] Sustainable biogenic sources include paper and wood products from sustainably managed forests. When these materials are burned or aerobically decomposed to CO_2, the CO_2 emissions are not counted. Our approach to measuring GHG emissions from biogenic sources is described in detail in Chapter 1.

[20] For details on the sensitivity analyses, see section 7.5 and Exhibits 7-7 and 7-8.

- A town of 50,000 landfilling 30,000 tons per year could install a landfill gas recovery system and reduce emissions by about 6,000 MTCE per year.
- At the national level, if the United States attains the goal of a 35 percent recycling rate by 2005, emissions will be reduced by nearly 10 million MTCE per year compared to a baseline where we maintain the current 30 percent recycling rate and use the "national average" landfill for disposal.

ES.7 OTHER LIFE-CYCLE GHG ANALYSES AND TOOLS

Life-cycle analysis is being used increasingly to quantify the GHG impacts of private and public sector decisions. In addition to the life-cycle analyses that underpin the emission factors in this report, Environmental Defense,[21] ICLEI, Ecobilan, and others have analyzed the life-cycle environmental impacts of various industry processes (e.g., manufacturing) and private and public sector practices (e.g., waste management). In many cases, the results of life-cycle analyses are packaged into software tools that distill the information according to a specific user's needs.

As mentioned earlier, the WARM model was designed as a tool for waste managers to weigh the GHG impacts of their waste management practices. As a result, the model focuses exclusively on waste sector GHG emissions, and the methodology used to estimate emissions is consistent with international and domestic GHG accounting guidelines. Life-cycle tools designed for broader audiences necessarily include other sectors and/or other environmental impacts, and are not necessarily tied to the Intergovernmental Panel on Climate Change (IPCC) guidelines for GHG accounting or the methods used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

- WARM, developed by ICF Consulting for EPA, allows users to input several key variables (e.g., landfill gas collection system information, electric utility fuel mix, transportation distances).[22] The model covers 21 types of materials and 5 waste management options: source reduction, recycling, combustion, composting, and landfilling. WARM accounts for upstream energy and non-energy emissions, transportation distances to disposal and recycling facilities, carbon sequestration, and utility offsets that result from landfill gas collection and combustion. The tool provides participants in the U.S. Department of Energy's 1605b program with the option to report results by year, by gas, and by year and gas. WARM software is available free of charge in both a Web-based calculator format and a Microsoft Excel© spreadsheet. The tool is ideal for waste planners interested in tracking and reporting voluntary GHG emission reductions from waste management practices and for comparing the climate change impacts of different approaches. To access the tool, visit: <http://www.epa.gov/globalwarming/actions/waste/warm.htm>.
- ICLEI Cities for Climate Protection (CCP) Campaign Greenhouse Gas Emission Software was developed by Torrie Smith Associates for ICLEI. This Windows-based tool, targeted for use by local governments, can analyze emissions and emission reductions on a community-wide basis and for municipal operations alone. The

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[21] Blum, L., Denison, R.A., and Ruston, V.F. 1997. A Life-Cycle Approach to Purchasing and Using Environmentally Preferable Paper: A Summary of the Paper Task Force Report," *Journal of Industrial Ecology*. I:3:15-46. Denison, R.A. 1996. "Environmental Life-Cycle Comparison of Recycling, Landfilling, and Incineration: A Review of Recent Studies;" Annual Review of Energy and the Environment 21:6:191-237.

[22] Microsoft Excel and Web-based versions of this tool are available online at the following Web site: http://www.epa.gov/globalwarming/actions/waste/tools.html.

community-wide module looks at residential, commercial, and industrial buildings, transportation activity, and community-generated waste. The municipal operations module looks at municipal buildings, municipal fleets, and waste from municipal in-house operations. In addition to computing GHG emissions, the CCP software estimates reductions in criteria air pollutants, changes in energy consumption, and financial costs and savings associated with energy use and other emission reduction initiatives. A version of the software program was made available for use by private businesses and institutions during the summer of 2001. CCP software subscriptions, including technical support, are available to governments participating in ICLEI for a subsidized price of $240. The full retail price of the software in the United States is $2,000. For more information, visit: <http://www.iclei.org/us/ccpsoftware.html> or contact the U.S. ICLEI office at (510)-540-8843, iclei_usa@iclei.org.

- The MSW Decision Support Tool (DST) and life-cycle inventory database for North America have been developed through funding by ORD through a cooperative agreement with the Research Triangle Institute (CR823052). The methodology is based on a multi-media, multi-pollutant approach and includes analysis of GHG emissions as well as a broader set of emissions (air, water, and waste) associated with MSW operations. The MSW-DST is available for site-specific applications and has been used to conduct analyses in several states and 15 communities including use by the U.S. Navy in the Pacific Northwest. The tool is intended for use by solid waste planners at state and local levels to analyze and compare alternative MSW management strategies with respect to cost, energy consumption, and environmental releases to the air, land, and water. The costs are based on full cost accounting principles and account for capital and operating costs using an engineering economics analysis. The MSW-DST calculates not only projected emissions of GHGs and criteria air pollutants, but also emissions of more than 30 air- and water-borne pollutants. The DST models emissions associated with all MSW management activities, including waste collection and transportation, transfer stations, materials recovery facilities, compost facilities, landfills, combustion and refuse-derived fuel facilities, utility offsets, material offsets, and source reduction. The differences in residential, multi-family, and commercial sectors can be evaluated individually. The software has optimization capabilities that enable one to identify options that evaluate minimum costs as well as solutions that can maximize environmental benefits, including energy conservation and GHG reductions.

  At the time of the publication of this report, the life-cycle inventory (LCI) database for North America was to be released in 2002. Plans to develop a Web-based version are being considered. The MSW-DST provides extensive default data for the full range of MSW process models and requires minimum input data. However, these defaults can be tailored to the specific communities using site-specific information. The MSW-DST also includes a calculator for source reduction and carbon sequestration using a methodology that is consistent with the IPCC in terms of the treatment of biogenic CO_2 emissions. For more information, refer to the project Web site: <http://www.rti.org/units/ese/p2/lca.cfm#life> or contact Susan Thornloe, U.S. EPA, (919)-541-2709, thornloe.susan@epamail.epa.gov, or Keith Weitz, Research Triangle Institute, (919)-541-6973, kaw@rti.org.

- The Tool for Environmental Analysis and Management (TEAM), developed by Ecobilan, simulates operations associated with product design, processes, and activities associated with several industrial sectors. The model considers energy consumption, material consumption, transportation, waste management, and other factors in its evaluation of environmental impacts. Many private firms and some government agencies have used the model. Users pay a licensing fee of $3,000 and an annual maintenance contract of $3,000.

This model is intended for use in Europe and was not developed for use in North America. For more information, visit: <http://www.ecobalance.com/software/gb_software.html>.

ES.8 LIMITATIONS OF THE ANALYSIS

When conducting this analysis, we used a number of analytical approaches and numerous data sources, each with its own limitations. In addition, we made and applied assumptions throughout the analysis. Although these limitations would be troublesome if used in the context of a regulatory framework, we believe that the results are sufficiently accurate to support their use in voluntary programs. Some of the major limitations include the following:

- The manufacturing GHG analysis is based on estimated industry averages for energy usage, and in some cases the estimates are based on limited data. In addition, we used values for the average GHG emissions per ton of material produced, not the marginal emission rates per incremental ton produced. In some cases, the marginal emission rates may be significantly different.
- The forest carbon sequestration analysis deals with a very complicated set of interrelated ecological and economic processes. Although the models used represent the state-of-the-art in forest resource planning, their geographic scope is limited. Because of the global market for forest products, the actual effects of paper recycling would occur not only in the United States but in Canada and other countries. Other important limitations include: (1) the estimate does not include changes in carbon storage in forest soils and forest floors; (2) the model assumes that no forested lands will be converted to non-forest uses as a result of increased paper recycling; and (3) we use a point estimate for forest carbon sequestration, whereas the system of models predicts changing net sequestration over time.
- The composting analysis considers a small sampling of feedstocks and a single compost application (i.e., agricultural soil). The analysis did not consider the full range of soil conservation and management practices that could be used in combination with compost and their impacts on carbon storage.
- The combustion analysis uses national average values for several parameters; variability from site to site is not reflected in our estimate.
- The landfill analysis (1) incorporates considerable uncertainty on CH_4 generation and carbon sequestration, due to limited data availability; and (2) uses landfill estimated CH_4 recovery levels for the year 2000 as a baseline.

Finally, throughout most of the report, we express analytical inputs and outputs as point estimates. We recognize that a rigorous treatment of uncertainty and variability would be useful, but in most cases the information needed to treat these in statistical terms is not available. The report includes some sensitivity analyses to illustrate the importance of selected parameters and expresses ranges for a few other factors such as GHG emissions from manufacturing. We encourage readers to provide more accurate information where it is available; perhaps with additional information, future versions of this report will be able to shed more light on uncertainty and variability. Meanwhile, we caution that the emission factors reported here should be evaluated and applied with an appreciation for the limitations in the data and methods, as described at the end of each chapter.